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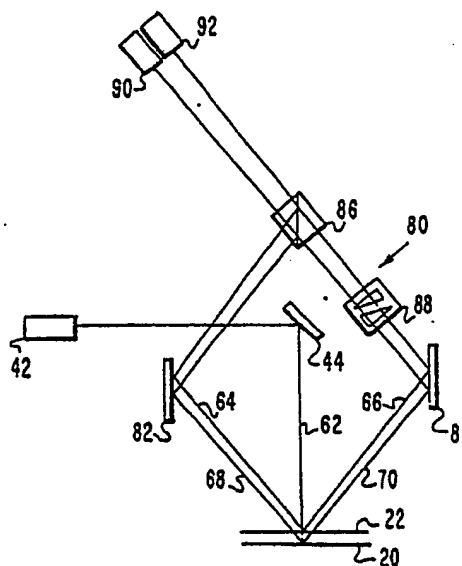


## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<table style="width: 100%; border: none;"> <tr> <td style="width: 50%; vertical-align: top; padding: 5px;"> <p>(21) International Application Number: PCT/US84/01542</p> <p>(22) International Filing Date: 26 September 1984 (26.09.84)</p> <p>(31) Priority Application Number: 590,135</p> <p>(32) Priority Date: 16 March 1984 (16.03.84)</p> <p>(33) Priority Country: US</p> <p>(71) Applicant: HUGHES AIRCRAFT COMPANY [US/US]; 200 North Sepulveda Boulevard, El Segundo, CA 90245 (US).</p> <p>(72) Inventor: BARTELT, John, L. ; 1504 Folkstone Terrace, Westlake Village, CA 91361 (US).</p> <p>(74) Agents: COLLINS, David, W. et al.: Hughes Aircraft Company, P.O. Box 1042, Bldg. C-2, MS A-126, El Segundo, CA 90245 (US).</p> </td> <td style="width: 50%; vertical-align: top; padding: 5px;"> <p>(81) Designated States: AT (European patent), AU, BE (European patent), BR, CH (European patent), DE (European patent), DK, FI, FR (European patent), GB (European patent), JP, LU (European patent), NL (European patent), NO, SE (European patent).</p> <p>Published With international search report.</p> </td> </tr> </table>			<p>(21) International Application Number: PCT/US84/01542</p> <p>(22) International Filing Date: 26 September 1984 (26.09.84)</p> <p>(31) Priority Application Number: 590,135</p> <p>(32) Priority Date: 16 March 1984 (16.03.84)</p> <p>(33) Priority Country: US</p> <p>(71) Applicant: HUGHES AIRCRAFT COMPANY [US/US]; 200 North Sepulveda Boulevard, El Segundo, CA 90245 (US).</p> <p>(72) Inventor: BARTELT, John, L. ; 1504 Folkstone Terrace, Westlake Village, CA 91361 (US).</p> <p>(74) Agents: COLLINS, David, W. et al.: Hughes Aircraft Company, P.O. Box 1042, Bldg. C-2, MS A-126, El Segundo, CA 90245 (US).</p>	<p>(81) Designated States: AT (European patent), AU, BE (European patent), BR, CH (European patent), DE (European patent), DK, FI, FR (European patent), GB (European patent), JP, LU (European patent), NL (European patent), NO, SE (European patent).</p> <p>Published With international search report.</p>
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<p>(54) Title: DISSIMILAR SUPERIMPOSED GRATING PRECISION ALIGNMENT AND GAP MEASUREMENT SYSTEMS</p>				

## (57) Abstract

A substrate (10) having a diffraction grating (20) of a first periodicity formed thereon, a mask (22) having a diffraction grating of a second periodicity formed thereon, the mask and substrate being positioned such that the respective mask and substrate gratings are generally parallel opposing one another on the mask and substrate, means (42) for providing collimated coherent light (24) directed so as to impinge on the mask and substrate gratings, and means for separately collecting (46, 48, 50, 52), recombining (54, 56) and detecting (58, 60) the intensity of at least a first given order of diffracted light beams as respectively diffracted by the mask and substrate gratings.



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DISSIMILAR SUPERIMPOSED GRATING PRECISION  
ALIGNMENT AND GAP MEASUREMENT SYSTEMS

1           The Government has rights in this invention  
pursuant to Contract No. N66001-82-C-0124 awarded by  
the Department of the Navy.

5                   BACKGROUND OF THE INVENTION

1. Field of the Invention

          The present invention relates generally to a  
precision overlay alignment system and, particularly,  
10   to proximity and projection lithography systems wherein  
ions, electrons or photons are utilized to transfer a  
high resolution pattern from a mask to a substrate.

2. Description of the Prior Art

15           There is a continuing desire to further reduce the  
minimum feature size of integrated circuits. This  
imposes a requirement of repeatably obtaining an exceed-  
ingly accurate degree of alignment between a mask and a  
substrate for each sequential lithographic step in the  
20   fabrication of an integrated circuit. For obtaining  
integrated circuits having feature sizes of below 1.0  
 $\mu\text{m}$ , an interferomic technique appears to possess  
the greatest likelihood of successful implementation.



1           D. C. Flanders et al., A New Interferomic Alignment  
Technique, Applied Physics Letters, Vol. 31, No. 7,  
1 October 1977, pp. 426-428, describes the basic inter-  
feromic technique. Diffraction gratings of identical  
5   period are provided on the facing surfaces of a mask  
and substrate. The gratings are generally oriented  
with respect to one another such that they are parallel.  
A beam of laser light is directed normal to the diffrac-  
tion grating planes with the result that diffracted  
10   light is returned at discrete angles from the incident  
laser beam, as may be determined by the equation:

$$n\lambda = d(\sin\phi_n - \sin\phi_i),$$

15   where  $n$  is the diffraction group number,  $\lambda$  is the  
incident beam wavelength,  $d$  is the grating period and  
 $\phi_n$  and  $\phi_i$  are the angles that the diffracted and  
incident beams make with respect to the normal of the  
diffraction grating planes. Only those beams suffering  
20   the smallest unit of an angular diffraction, those  
that have suffered a net first order diffraction, are  
utilized in the Flanders et al. technique. Further,  
the Flanders et al. technique utilizes the fact that  
the diffracted beams occur to either side of the incident  
25   laser beam. Thus, the first order diffraction group  
includes both plus ( $n = +1$ ) and minus ( $n = -1$ ) order  
beams. The plus first order diffraction group is  
composed of those beams that only suffer a plus first  
order diffraction from the mask grating (indicated as  
30   (1,0,0) in summary notation), or a sequential combination  
of diffractions such as a zeroth order diffraction  
from the mask grating, a plus first order diffraction  
from the substrate grating, and a zeroth order diffraction  
returning through the mask grating (0,1,0). The plus  
35   first order diffraction group may also include such

1 beams that have sequentially suffered a zeroth order  
diffraction through the mask grating, a minus first  
order diffraction from the substrate grating, and a  
plus second order diffraction through the mask grating  
5 (0,-1,2). The result is an effective or net plus  
first order diffraction. Due to the symmetry of the  
gratings, a generally symmetrical set of beams are  
diffracted by the mask and wafer gratings so as to  
form both plus and minus first order diffraction groups.  
10 The Flanders et al. technique measures the relative  
difference in the plus and minus first order diffraction  
group intensities to obtain an indication of the alignment  
of the mask and substrate gratings. For an in-plane  
displacement of the mask with respect to the substrate  
15 less than the period of the gratings, there is a corres-  
ponding variation in the relative intensities of the  
plus and minus first order diffraction groups due to  
the mutual interference between beams within each  
group. Ideally, there is a zero intensity difference  
20 between the plus and minus first order diffraction  
groups only when the mask and substrate diffraction  
grating lines are aligned. With the detection of  
sufficiently small intensity differences Flanders et al.  
concludes that alignment errors as small as 200Å can be  
25 detected.

There are, however, a number of inherent problems  
with the Flanders et al. technique. Of principal  
significance is that the Flanders et al. technique is  
highly sensitive to the specific spacing between the  
30 mask and substrate. In practical applications, this  
gap distance may vary due to bowing of the mask or  
wafer, or both, the tolerance errors in the machinery  
positioning the mask and substrate (particularly in  
such systems where there is a substrate step and repeat  
35 exposure sequence), and such transient perturbations



1 as due to thermal, acoustic, and mechanical vibrations.  
These sources of gap distance variations further compound  
the simple fact that a gap exists at all. This inter-  
ferometric technique relies on the interference between  
5 the respective first order diffracted group beams  
diffracted from the mask grating with those from the  
substrate grating. Since there is a spacing between  
the mask and substrate gratings, there is an inherent  
difference in the path length traversed by the respective  
10 mask and substrate grating diffracted beams. This  
introduces an effective phase retardation in those  
beams diffracted by the substrate grating. Thus, the  
interference that naturally occurs between the mask  
and substrate diffracted beams produces an equal intensity  
15 change but of opposite effective polarity in the respec-  
tive plus and minus group beams. Consequently, when  
the mask and substrate gratings are in fact aligned,  
there will be an inherent difference in the intensities  
of the plus and minus first order diffraction group  
20 beams due to the presence of the gap.

While a constant difference in intensity might be  
appropriately dealt with, assuming the gap distance can  
be accurately and independently quantitized, the various  
causes of variations in the mask to substrate spacing  
25 are essentially random transients not subject to practical  
quantitization. Further, the variations in spacing  
are typically an appreciable fraction of the otherwise  
nominal gap distance. Consequently, there is no practical  
way to discriminate between mask and substrate grating  
30 alignment errors and the undesirable but nonetheless  
present variations in the mask to substrate spacing.

Another practical problem with the Flanders et  
al. technique is that it requires the diffraction  
efficiency of both the mask and substrate gratings to  
35 remain essentially constant and equal throughout the



1 processing of the substrate. The efficiency of the  
mask grating may change due to the simple fact that  
different masks are utilized for the different sequential  
lithographic processing steps. However, the variations  
5 in mask grating efficiency alone are tolerable. In  
contrast, the effective diffraction efficiency of the  
substrate grating is reduced by the simple fact that  
the substrate grating diffracted beams must pass twice  
through the mask grating. Further the substrate grating  
10 is utilized throughout the processing of the substrate  
and, therefore, is effectively exposed to the effects  
of all of the processing steps. Thus, the substrate  
grating efficiency degrades as the processing proceeds.  
Degradation of substrate grating efficiency results in  
15 a loss of its diffracted beam intensity and, thereby  
reduces the interference modulation of the plus and  
minus group beams. Consequently, for a given detector  
sensitivity, loss of grating efficiency directly increases  
the minimum limit of alignment error that can be detected.

20

#### SUMMARY OF THE INVENTION

The general purpose of the present invention is  
to provide a highly accurate lithography alignment  
system of practical utility.

25 This is accomplished by the present invention by  
providing a mask and substrate alignment system comprising  
a substrate having a diffraction grating of a first  
periodicity formed thereon, a mask having a diffraction  
grating of a second periodicity formed thereon, the  
30 mask and substrate being positioned such that the  
respective mask and substrate gratings are generally  
parallel opposing one another on the mask and substrate,  
means for providing collimated coherent light directed  
so as to impinge on the mask and substrate gratings,  
35 and means for separately collecting, recombining, and





1 detecting the intensity of at least a first given order  
of diffracted light beams as respectively diffracted  
by the mask and substrate gratings. An indication of  
alignment between the mask and substrate gratings is  
5 obtained by comparing the relative intensity of the  
beams effectively diffracted only by the mask with  
those only effectively diffracted by the substrate  
with regard to their respective maximum obtainable  
intensities for their given diffracted beam orders.

10 Thus, the present invention retains the elemental  
simplicity of design and the capability for precision  
alignment present in the basic interferometric technique.

Another advantage of the present invention is  
that it is insensitive to the presence of a gap between  
15 the mask and substrate grating in positioning the  
substrate with respect to the mask and, further, any  
transient variations in the gap distance within reasonable  
limits.

A further advantage of the present invention is  
20 that it is substantially insensitive to an initial  
difference and subsequent variations in the diffraction  
efficiency of the mask and substrate gratings.

Yet another advantage of the present invention is  
that it permits the direct measurement of the gap  
25 spacing between the mask and substrate during the  
positioning and subsequent maintenance of the substrate  
with respect to the mask.

A still further advantage of the present invention  
is that it is adaptable to a wide variety of proximity  
30 and projection lithography systems.

1                    BRIEF DESCRIPTION OF THE DRAWINGS

                  These and other attendant advantages of the present invention will become apparent and readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, in which like reference numerals designate like parts throughout the figures and wherein:

                  FIG. 1a is a perspective view of a portion of a diffraction grating as used in the present invention;

                  FIG. 1b shows the coordinate system to be used in describing the orientation of the diffraction gratings utilized in the present invention;

                  FIG. 2 is a schematic representation of the dissimilar superimposed diffraction gratings and the diffraction of light therefrom;

                  FIG. 3 is a diagrammatic view of a first embodiment of an apparatus employing the present invention; and

                  FIG. 4 is a diagrammatic view of an optimized optical path embodiment of an apparatus employing the present invention.

DETAILED DESCRIPTION OF THE INVENTION

25                   The present invention was developed for use in a proximity type high resolution masked ion beam lithography (MIBL) system. Typically, such a system includes a collimated ion beam source, a relatively immobile ion-channeling replication mask, and an x-y translation stage including a mount for holding a substrate. In accordance with the present invention, the substrate is preprocessed to form gratings thereon substantially as represented in FIG. 1a. The gratings can be formed, using ordinary photolithographic techniques as a simple resist pattern on the surface of the substrate or



1 etched directly into either the surface of the substrate  
or a layer formed thereon. Preferably, the diffraction  
grating is etched permanently into the substrate so as  
to provide a pattern having a constant period  $d$  of  
5 approximately  $2\text{ }\mu\text{m}$  and a line width of  $d/2$ . The  
height  $h$  of the diffraction grating lines is generally  
selected to optimize its reflective diffraction efficiency  
with respect to a given diffraction order, preferably  
the first, and, as such, is selected depending on the  
10 wavelength of the incident alignment light beam, the index  
of refraction of the substrate and any layers thereon.  
Preferably, the source of incident alignment light is  
a low power laser producing a well collimated beam of  
coherent light. While a variety of lasers may be  
15 used, such as HeNe and  $\text{Ar}^+$ , to provide an alignment  
light beam at any one of a wide range of frequencies,  
a HeNe laser emitting light having a wavelength of  
approximately 632.8 nanometer is preferred. For a  
diffraction grating etched into a silicon substrate,  
20 and generally meeting the above criteria, this incident  
beam wavelength corresponds to a diffraction grating  
line height  $h$  of approximately  $3000\text{\AA}$ .

The mask grating is formed as a relief pattern  
provided as part of the ion-channeling mask. Dissimilar  
25 grating periods are chosen for the mask and substrate  
gratings in accordance with the present invention.  
The period of the mask grating is preferably chosen to  
be larger than that of the substrate to obtain the  
greater transmission efficiency inherent with relatively  
30 larger grating periods and, thereby, optimize the  
amount of zeroth order diffraction light passing through  
the mask grating. The basis for the selection of the  
two dissimilar grating periods will become apparent  
from the discussion below. Preferably, the mask grating  
35 period  $d$  is chosen as approximately equal to  $3\text{ }\mu\text{m}$

- 1 with a line width of  $d/2$  or  $1.5 \mu\text{m}$ . The height  $h$  and,  
in particular, the cross sectional shape of the mask  
grating lines are selected to balance the diffraction  
efficiency between the zeroth order transmission of  
5 the incident beam and the reflective diffraction of  
first order diffraction beams.

- The mask and substrate are overlaid in close  
proximity to one another so as to superimpose the  
dissimilar gratings of the mask and substrate.
- 10 Preferably, pairs of gratings are provided along each  
edge of the mask and oriented within the plane of the  
mask at  $90^\circ$  with respect to one another. Substrate  
gratings are correspondingly located and oriented.  
This allows orientation of the mask and substrate in  
15 both the  $x$  and  $y$  direction of the coordinate system  
indicated in FIG. 1b. As will be explained below,  
this further allows for the proper rotational or theta  
alignment of the mask and substrate. As will also be  
explained in greater detail below, alignment of the mask  
20 and substrate in the  $z$  direction is essentially  
noncritical for  $x$ - $y$  alignment. The present invention,  
however, provides for precision  $z$  distance measurement  
and alignment that is substantially insensitive to the  $x$ - $y$   
relative location of the gratings.

- 25 Referring now to FIG. 2, a schematic representation  
of the diffraction of an incident beam of light 24 from  
dissimilar superimposed gratings 20, 22 is shown. The  
direction of the beams generated by the diffraction of  
the incident beam 24 is given by:

30

$$n\lambda = d(\sin\phi_n - \sin\phi_i), \quad (1)$$

- where  $n$  is the diffraction group number,  $\lambda$  is the  
incident beam 24 wavelength,  $d$  is the grating period and  
35  $\phi_n$  and  $\phi_i$  are the angles that the diffracted and  
incident beams make with respect to the normal of the



- 1 diffraction grating planes. Considering for purposes  
of the present invention only the first order diffraction  
group and selecting  $\phi_1 = 0$ , the diffracted beam  
angles  $\phi_1, \phi_2$  from the plane of the incident  
5 beam 24 normal to the mask and substrate gratings and  
parallel to the length of the diffraction grating  
lines is given by:

$$\phi_n = \sin^{-1}(\lambda/d). \quad (2)$$

- 10 The use of dissimilar superimposed diffraction gratings  
thus results in the spatial separation of the respective  
plus and minus first order diffraction beams as respec-  
tively diffracted from the substrate grating 20 and  
the mask grating 22. For the preferred incident beam  
15 24 wavelength and the preferred grating periods as  
noted above,  $\phi_1$  is equal to approximately  $12.18^\circ$   
and  $\phi_2$  equals approximately  $18.44^\circ$ . The selection  
of the particular grating periods is based on the  
practical considerations of providing sufficient spatial  
20 separation between the respective plus and minus first  
order diffracted beams 26, 30, and 28, 32 so as to  
permit their subsequent manipulation in accordance  
with the present invention. The selection of the  
grating periods is also based on the practical  
25 consideration that the capture range of the alignment  
technique of the present invention is approximately  
one-half of the smaller of the two grating periods.  
The relative phase of the plus and minus order diffracted  
beams directed at diffraction angles given by Equation 2  
30 for a given order will vary as the position of the  
corresponding diffraction grating is shifted laterally.  
The plus and minus order beams are coherently recombined  
with the result that the position information is converted  
to an intensity variable by mutual coherent interference.  
35 The magnitude of the beam intensity and the position



1 of a grating can be related by deriving the time averaged  
Poynting vector magnitude for the recombined diffracted  
beams. In the context of the present invention for the  
mask grating alone (or, in the presence of the substrate  
5 grating, where the reflected zeroth order substrate  
grating reflectively diffracted beam is otherwise  
blocked) or the substrate grating either in the presence  
or absence of the mask grating, the time average Poynting  
vector magnitude is:

10 
$$|\bar{S}| = \cos^2\left(\frac{2\pi\epsilon}{d}\right) \quad (3)$$

where  $\epsilon$  is the lateral displacement and  $d$  is the grating  
period of the corresponding displaced grating. The  
cosine squared function evaluates to two complete cycles  
15 of intensity as  $\epsilon$  goes from zero to  $d$ . Consequently,  
a nonambiguous alignment position can only be obtained  
if the superimposed dissimilar gratings are initially  
aligned with respect to one another within one-half of  
the period of the smaller of the two gratings.

20 In order to increase the capture range, larger  
grating periods can be utilized. In the case of grating  
periods of 10 and 11  $\mu\text{m}$  for the substrate and mask  
gratings, respectively, a capture range of approximately  
5  $\mu\text{m}$  can be obtained. However, the spatial separation  
25 of the first order diffracted beams as diffracted from  
the mask and the substrate gratings, respectively, are  
substantially reduced. The first order diffraction  
angle for a diffraction grating of 10  $\mu\text{m}$  is approximately  
3.63° and, for a grating of a period of 11  $\mu\text{m}$ , the  
30 diffraction angle is approximately 3.29°, based on an  
incident beam wavelength of 632.8 nanometers.



1           Another consideration in choosing the periods of  
the dissimilar diffraction gratings is that the larger  
diffraction grating periods inherently are associated  
with a lower diffraction efficiency. This results in  
5 a significant reduction of the available diffracted  
beam intensity. Preferably, for a grating pair, the  
smaller grating period is  $np$  and the larger is  $np+1$ ,  
where  $n$  is an integer and  $p$  is a unit length on the  
order of a micrometer.

10           In view of the foregoing, an optimal solution to  
the choice of dissimilar diffraction grating periods is  
to simply provide multiple pairs of superimposed  
dissimilar gratings of, preferably, 2 and 3  $\mu\text{m}$  periods  
and 10 and 11  $\mu\text{m}$  periods, respectively. This allows  
15 the larger capture range of the larger grating period  
pair to be utilized to place the mask and substrate in  
sufficient alignment to be within the capture range of  
the greater available precision of the smaller grating  
period pair. Thus, the advantages of using both the  
20 large and small dissimilar grating periods are obtained.

It is important to recognize from Equation 3 that  
the intensity magnitude of a recombined beam is dependent  
only on the lateral position of a single corresponding  
grating and not at all dependent on the gap distance  
25 between the mask and substrate gratings. Thus, for those  
cases noted above in which Equation 3 applies, the  
determination of alignment is independent of the presence  
of a mask to substrate gap or any variation therein.

In the sole case where zeroth order mask transmitted  
30 beam is returned back through the mask as a zeroth  
order substrate grating diffracted beam, there will be  
a detectable variation in the intensity of the mask  
diffracted and subsequently recombined beam as measured  
at the mask position detector. The zeroth order trans-  
35 mitted beam may be returned by a reflective zeroth order

1 diffraction from the substrate grating or, in the  
 absence of any substrate grating, simply reflected by a  
 specular area of the substrate. This reflected zeroth  
 order beam will be diffracted, at least in part, by the  
 5 mask grating, thereby, producing plus and minus first  
 order diffracted beams (0,0, $\pm 1$ ). These beams will  
 mutually interfere with the corresponding singly  
 diffracted first order beams ( $\pm 1,0,0$ ) diffracted  
 by the mask. Consequently, the recombined mask first  
 10 order diffracted beam intensity will have a Poynting  
 vector magnitude given by:

$$|\vec{S}| = 2(1 + 2\cos 2\phi), \quad (4)$$

where

$$15 \quad \phi = g\left(\frac{2\pi}{\lambda}\right) \left[ 1 - \sqrt{1 - \left(\frac{\lambda}{d}\right)^2} \right], \quad (5)$$

and where  $g$  is the gap spacing,  $\lambda$  is the wavelength of  
 the incident beam, and  $d$  is the period of the mask  
 diffraction grating. Thus, assuming the position of  
 20 the mask grating is first established, the present  
 invention permits the accurate measurement of the mask  
 to substrate gap spacing  $g$  based on the measured intensity  
 of the recombined mask diffracted beam. Of particular  
 advantage is that the gap measurement is essentially  
 25 independent of the specific lateral position of the  
 substrate grating.

Referring now to FIG. 3, a complete optical system  
 embodying the present invention is shown schematically.  
 The alignment apparatus 40 includes a laser source 42  
 and an incident beam mirror 44 arranged to direct an  
 30 incident beam 62 toward the substrate and mask gratings  
 20, 22. The substrate and mask gratings 20, 22, shown  
 not to scale, diffract the first order diffracted  
 beams toward corresponding collection mirrors 46, 48,

35





1 50, 52. The respective collection mirror pairs 46, 48  
and 50, 52 collect the respective plus and minus first  
order diffracted beam pairs 64, 66 and 68, 70 and  
redirect them to the beam splitters/recombiners 54,  
5 56, respectively. The separate first order diffracted  
beams are recombined by mutual coherent interference  
at their respective beam splitters 54, 56 and pass on  
to the detectors 58, 60. These detectors are preferably  
semiconductor opto-detectors selected as being sensitive  
10 to optical radiation of the same wavelength as the  
light emitted by the laser light source 42. Since the  
grating periods of the substrate and mask gratings 20,  
22 are dissimilar and by the unique placement of the  
collection mirrors 46, 48, 50, 52, only the first  
15 order diffracted beams that have further suffered only  
a single non-zero order diffraction are collected.  
All higher order diffracted beams as well as all first  
order diffraction group beams that have been multiply  
diffracted will emerge from the substrate and mask  
20 gratings at sufficiently different spatially distributed  
diffraction angles to permit the selection of only the  
first order singly diffracted beams  $64(-1,0,0)$ ,  $66(1,0,0)$   
and  $68(0,-1,0)$ ,  $70(0,1,0)$ . The placement of the collec-  
tion mirrors 46, 48, 50, 52 and the beam splitters 54,  
25 56, is further selected such that there is a common  
path length for both the plus and minus first order  
singly diffracted beams that are respectively diffracted  
from the mask and substrate gratings 20, 22. Naturally,  
the coherence length of the laser light source 42 must  
30 be greater than the optical path length from the laser  
42 to either detector 58, 60.

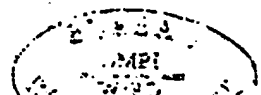
1           An alternate embodiment of the present invention  
is shown in FIG. 4. The alignment system 80 again  
includes the laser source 42 and incident beam mirror  
44 for directing an incident laser beam 62 so as to  
5   impinge on the dissimilar superimposed substrate and  
mask gratings 20, 22. A single pair of collection  
mirrors 82, 84 are positioned to collect the respective  
minus and plus first order singly diffracted beams  
64(-1,0,0), 68(0,-1,0) and 66(1,0,0), 70(0,1,0) and  
10   redirect them along separate optical paths to a common  
beam splitter/recombiner 86. The respective first  
order singly diffracted beams are effectively recombined  
by mutual coherent interference at the beam splitter  
86 and directed to respective detectors 90, 92. Similar  
15   to the previous alignment system 40, the collection  
mirrors 82, 84 are positioned so as to collect only  
the first order singly diffracted light from the mask  
and wafer gratings 22, 20. Path length compensation  
is accomplished by the provision of a standard Soleil-  
20   Babinet compensator placed in the path of the plus  
first order singly diffracted beams 66, 70 from the  
mask and substrate gratings 22, 20. Thus, path length  
compensation is obtained relatively independent of the  
placement of the collection mirrors 82, 84. Consequently,  
25   the placement of the collection mirrors 82, 84 may be  
optimized so as to collect only the first order singly  
diffracted group 64, 66, 68, 70.

          In a practical application, a number of alignment  
systems 40 or 80 are utilized as subsystems within a  
30   lithography system, such as MIBL. Each alignment  
subsystem is utilized to derive x or y alignment  
information from a corresponding superimposed dissimilar  
diffraction grating pair. Preferably, at least four



1 such subsystems are utilized with four corresponding  
dissimilar superimposed grating pairs spaced equally  
about the periphery of a typically square area, the  
diagonally disposed grating pairs sharing a common  
5 grating line orientation that is rotated in-plane  $90^\circ$   
from that of the other two grating pairs.

In operation, an initial alignment between a  
mask and a substrate is obtained by first moving the  
mask in a given x direction and observing the intensity  
10 phase change at the corresponding detectors. At this  
point, the return of any zeroth order mask grating  
transmitted beam must be prevented as may be accomplished  
by simply not providing the substrate in the vicinity  
of the mask. The mask grating can be moved by physically  
15 translating the position of the mask. Preferably,  
however, the effective position of the mask can be  
modified by adjusting the relative path length of the  
plus and minus first order singly diffracted beams.  
This may be accomplished through the use of the compen-  
20 sator 88 of FIG. 4. Positioning the compensator 88 so  
as to modify the corresponding plus first order singly  
diffracted beams 66, 70 from the mask and substrate,  
respectively, prevents the introduction of a relative  
path length difference error thereinbetween. Thus, as  
25 the mask grating is laterally displaced, effectively  
or otherwise, the recombined mask beam detector 92  
will observe a sinusoidal variation in the intensity  
of the recombined first order singly diffracted beam  
incident thereon. Any phase point along the sinusoidal  
30 variation in intensity can be selected as a null position  
point. If necessary, the mask may be rotated as well  
as shifted, effectively or otherwise, so that a common  
null point is observed by the detector of both of the  
x direction subsystems. A y direction mask null point  
35 is similarly selected. The substrate is then moved



1 into the vicinity of the mask so as to superimpose the  
gratings within the appropriate capture range. Null x  
and y positions for the substrate x and y direction  
gratings are then selected similarly. Although the  
5 present invention permits the x and y phase point  
nulls of the mask to be selected independently of one  
another as well as either of the x and y phase point  
nulls of the substrate, preferably all of the phase  
point nulls are selected to be 90° past the maximum  
10 intensity obtainable at their respective detectors  
when moved within their capture ranges in a given x or  
y direction. Subsequent alignments between the mask  
and substrate are accomplished by placing the mask and  
substrate in sufficiently close alignment, in both the  
15 x and y directions, so as to again be within the capture  
ranges of the various dissimilar superimposed diffraction  
gratings. The substrate is then again translated in  
the x and y directions until the intensities measured  
at the various detectors correspond substantially to  
20 the intensity phase point nulls selected during the  
initial alignment.

Consistent with the foregoing, during the  
positioning for and subsequent maintenance of the  
aligned position of the substrate, the mask to substrate  
25 gap spacing can be measured and continually monitored  
by observing the intensity of the mask signal at the  
recombined mask beam detector 92 in view of Equations  
4 and 5. Naturally, the position of the substrate can  
be modified as necessary to obtain the desired gap  
30 spacing and plane parallelism between the mask and  
substrate.

The present invention thus provides a method of  
obtaining interferomic precision alignment between  
dissimilar period superimposed diffraction gratings  
35 that can be implemented in a simple and highly reliable



1 optical system. As such, the present invention permits  
the precision alignment of the dissimilar superimposed  
diffraction gratings to be obtained and maintained  
substantially independent of variations in the spacing  
5 between the relative diffraction efficiency of the  
dissimilar period gratings. Further, the present  
invention permits the interferomic precision measurement  
of and, thereby, control of the mask to substrate gap  
spacing.

10 It should be understood, of course, that the  
foregoing is a description of the preferred embodiments  
of the present invention and that many modifications  
and variations are possible in light of the above  
teachings. These modifications and variations include,  
15 but are not limited to, utilizing laser light sources  
of different selected wavelengths, folding the optical  
path of the alignment system so as to obtain nonsymme-  
trical diffraction from the mask and substrate gratings,  
positioning the optics to collect, recombine, and detect  
20 diffraction order beams of one given order to obtain a  
mask position signal and of another given order to  
obtain a substrate position signal, utilizing different  
materials to form the mask, pairing mask gratings with  
plane substrate surfaces to obtain gap measurement  
25 sites alone or separate from dissimilar grating alignment  
sites, and utilizing the present invention in other  
proximity and projection pattern replicating lithography  
systems. It is therefore to be understood that, within  
the scope of the appended claims, the invention may be  
30 practiced otherwise than is specifically described  
above.

CLAIMSWhat is Claimed is:

- 1 1. A proximity interferomic alignment system  
comprising:
- a) a substrate having a diffraction grating  
of a first periodicity formed thereon;
- 5 b) a mask having a diffraction grating of a  
second periodicity formed thereon, said mask and  
substrate being provided in close proximity to one  
another so as to substantially superimpose said mask  
and substrate gratings;
- 10 c) means for providing a collimated coherent  
lightbeam directed so as to impinge on said mask and  
substrate gratings; and
- d) means for separately collecting, recom-  
bining, and detecting the intensity of a first given  
15 order of singly diffracted lightbeams as diffracted by  
said mask grating and of a second given order of singly  
diffracted lightbeams as diffracted by said substrate  
grating.
- 1 2. The interferomic alignment system of Claim 1  
further comprising:
- a) means for adjusting the in-plane position  
of said mask with respect to said collecting, recombining  
5 and detecting means; and
- b) means for adjusting the in-plane position  
of said substrate with respect to said collecting,  
recombining and detecting means.
- 1 3. The interferomic alignment system of Claim 2  
further characterized in that said mask and substrate  
gratings are provided on respective facing surfaces of  
said mask and said substrate.



1           4. The interferomic alignment system of Claim 1 further characterized in that the periods of said masks and substrate gratings are between approximately one and fifteen microns.

1           5. The interferomic alignment system of Claim 4 further characterized in that the periods of said mask and substrate gratings differ by approximately one micron.

1           6. The interferomic alignment system of Claim 1 further characterized in that said first given order and said second given order of diffracted light both correspond to first order singly diffracted light from said mask and said substrate gratings, respectively.

1           7. An interferomic alignment system for the precision alignment of a first element with a second element comprising:

5           a) a first diffraction grating of a first periodicity associated with said first element;

          b) a second diffraction grating of a second periodicity associated with said second element;

10          c) means for positioning said first and second elements such that said first and second grating are superimposed with respect to one another;

          d) means for providing collimated coherent light directed so as to impinge on said first and second gratings;

15          e) collection optics for selecting and redirecting the plus and minus diffraction beam pairs of a first given diffraction order from said first grating and a second given diffraction order from said second grating;



20 f) recombination optics for receiving the  
redirected beam pairs from said collection optics and  
recombining the respective beam pairs by mutual coherent  
interference to obtain a first element recombined beam  
and a second element recombined beam, respectively; and

25 g) first and second detection means for  
separately detecting the intensity of said first and  
second element recombined beams, respectively.

1 8. The system of Claim 7 wherein said first and  
second diffraction gratings are provided in close  
proximity to one another as appropriate for use in a  
proximity lithography system.

1 9. The system of Claim 7 further comprising  
projection optics interposed between said first and  
second elements so as to permit the demagnified projection  
of a pattern from said first element to be imaged on  
said second element as appropriate in a projection  
5 lithography system.

1 10. The system of Claims 8 or 9 wherein the period  
of said second grating is essentially infinite with  
respect to that of said first grating.

1 11. An interferomic gap measurement system for  
the precision measurement of the distance between a first  
element and a second element comprising:

5 a) a diffraction grating of a given periodicity  
associated with said first element;

b) a reflective surface area associated with  
said second element;

10 c) means for positioning said first and  
second elements such that said grating is superimposed  
over and is substantially plane parallel with said  
reflective surface area;





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Fig. 1a.

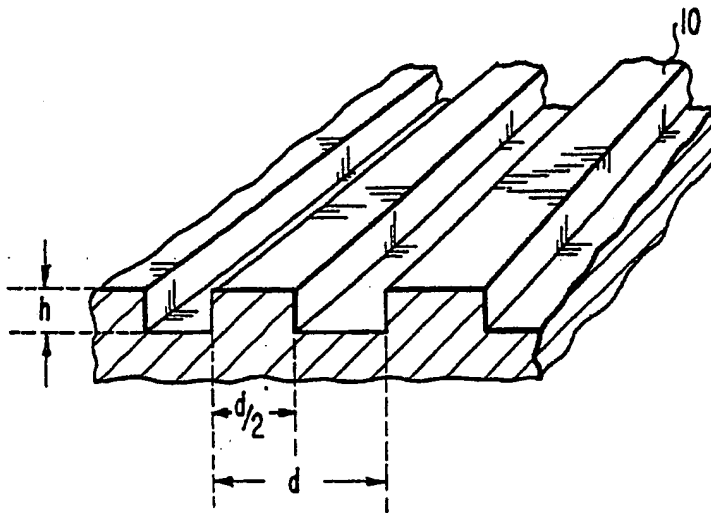


Fig. 1b.

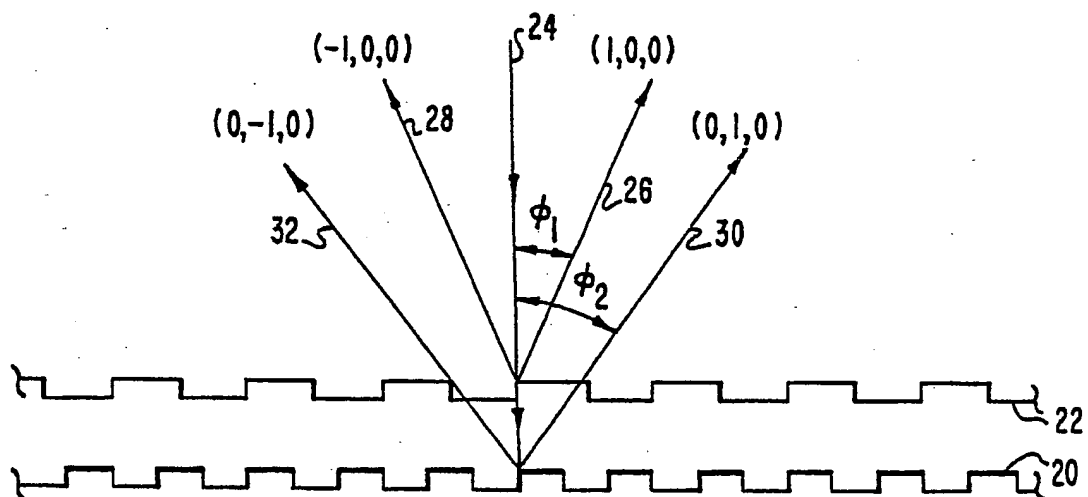
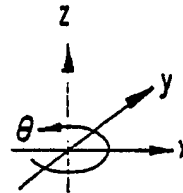


Fig. 2.

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Fig. 3.

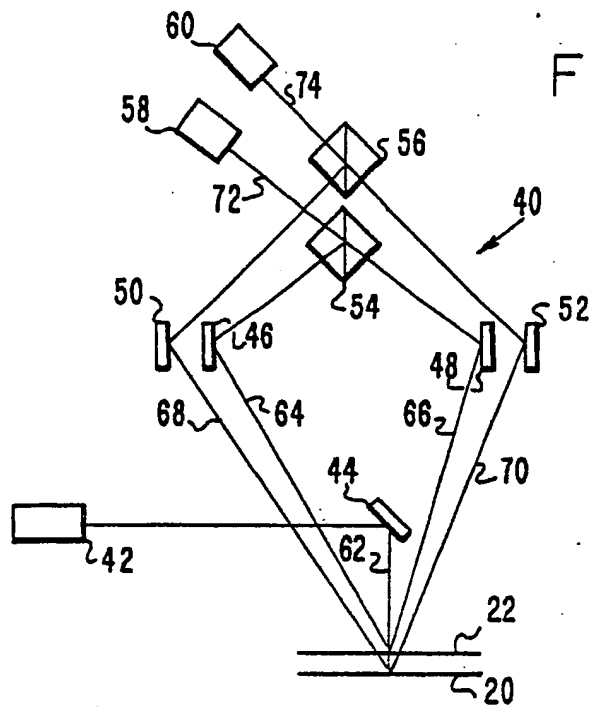
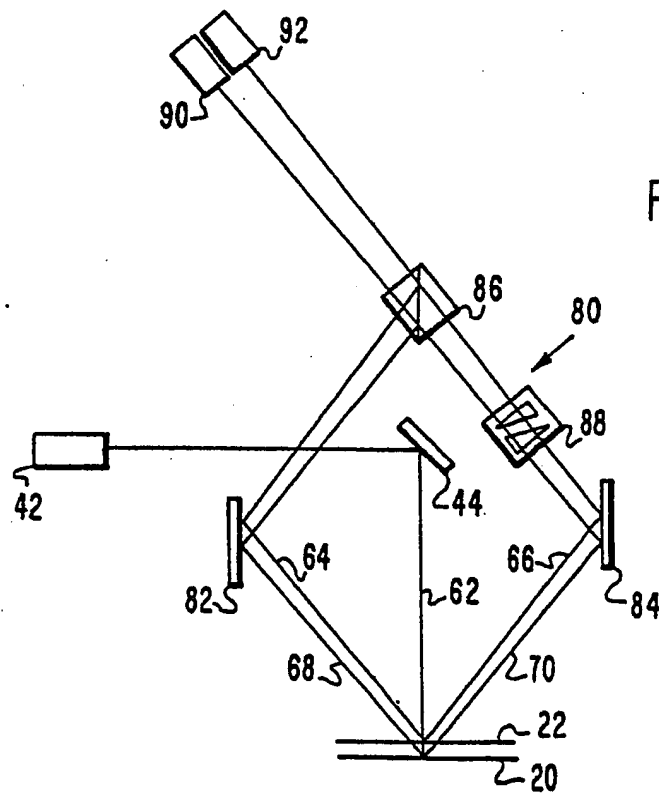


Fig. 4.



# INTERNATIONAL SEARCH REPORT

International Application No PCT/US 84/01542

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (If several classification symbols apply, indicate all) <sup>1</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC <sup>4</sup> :        G 03 B 41/00; G 01 B 11/27		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched *		
Classification System	Classification Symbols	
IPC <sup>4</sup>	G 03 B 41/00; G 05 D 3/00; G 01 B 11/27	
Documentation Searched other than Minimum Documentation to the extent that such Documents are included in the Fields Searched *		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> <sup>14</sup>		
Category *	Citation of Document, <sup>14</sup> with indication, where appropriate, of the relevant passages <sup>17</sup>	Relevant to Claim No. <sup>14</sup>
Y	Applied Physics Letters, vol. 31, no. 7, October 1977 (New York, US) D.C. Flanders et al.: "A new interferometric alignment technique", pages 426-428, see page 427, left-hand column, lines 1-19; figure 3 (cited in the application)	1,4,6,7,8,11
Y	US, A, 4200395 (SMITH) 29 April 1980 see column 4, line 64 - column 5, line 3; column 6, line 56 - column 8, line 47; column 9, lines 5-10; claim 3	1-3,7,8,11
A	US, A, 4251160 (BOUWHUIS) 17 February 1981 see abstract; page 1	9
A	EP, A1, 0010998 (THOMSON CSF) 14 May 1980 see figure 1	10
A	IBM Technical Disclosure Bulletin, vol. 23, no. 7A, December 1980 (New York, US) D.C. Hofer: "Coarse and fine align- ment using out-of-phase pair of optical ./.	
<p>* Special categories of cited documents: <sup>15</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"Δ" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search <sup>1</sup>		Date of Mailing of this International Search Report <sup>1</sup>
13th December 1984		19 FEB. 1985
International Searching Authority <sup>1</sup>		Signature of Authorized Officer <sup>20</sup>
EUROPEAN PATENT OFFICE		G.L.M. Kalyandarg

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, <sup>16</sup> with indication, where appropriate, of the relevant passages <sup>17</sup>	Relevant to Claim No <sup>18</sup>
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	gratings", pages 2996-2998, see the entire document -----	1
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Priority Applications (No Type Date): JP 83241263 A 19831221

Patent Details:

Patent No Kind Lan Pg Main IPC Filing Notes

JP 60133779 A 3

Title Terms: INTEGRATE; CIRCUIT; TYPE; SEMICONDUCTOR\*; LASER; OPTICAL;  
GUIDE; FORMING; DIFFRACTED; LATTICE; OPTICAL; RESONANCE; AXIS; DIRECTION;  
DIFFERENTIAL; NOABSTRACT

Derwent Class: U12; V08

International Patent Class (Additional): H01S-003/18

File Segment: EPI

1/5/4 (Item 4 from file: 351)

DIALOG(R)File 351:Derwent WPI

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004373677

WPI Acc No: 1985-200555/198533\*

Semiconductor\*laser device for optical communication - has emission  
portions controlled inlateral\*mode on same plane and optically  
connected usingdiffraction\*grating NoAbstract Dwg 3/3

Patent Assignee: HITACHI LTD (HITA )

Number of Countries: 001 Number of Patents: 001

Patent Family:

Patent No Kind Date Applicat No Kind Date Week

JP 60126881 A 19850706 JP 83233666 A 19831213 198533 B

Priority Applications (No Type Date): JP 83233666 A 19831213

Title Terms:SEMICONDUCTOR\*; LASER; DEVICE; OPTICAL; COMMUNICATE; EMIT;  
PORTION; CONTROL; LATERAL; MODE; PLANE; OPTICAL; CONNECT; DIFFRACTED;  
GRATING; NOABSTRACT

Derwent Class: U12; V08

International Patent Class (Additional): H01S-003/18

File Segment: EPI

1/5/5 (Item 1 from file: 347)

DIALOG(R)File 347:JAPIO

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06736914 \*\*Image available\*\*

OPTICAL SIGNAL DETECTOR AND OPTICAL PICKUP DEVICE

PUB. NO.: 2000-322761 [JP 2000322761 A]

PUBLISHED: November 24, 2000 20001124)\*

INVENTOR(s): NISHINO SEIJI

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昭60-126881

⑬ Int.Cl.<sup>4</sup>

H 01 S 3/18

識別記号

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7377-5F

⑭ 公開 昭和60年(1985)7月6日

審査請求 未請求 発明の数 1 (全3頁)

⑮ 発明の名称 半導体レーザ装置

⑯ 特 願 昭58-233666

⑰ 出 願 昭58(1983)12月13日

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㉓ 代 理 人 弁理士 中村 純之助  
最終頁に続く

## 明 細 書

## 1. 発明の名称

半導体レーザ装置

## 2. 特許請求の範囲

横モード制御された複数個のレーザ発光部を同一面上に並置し、上記各レーザ発光部を周期性を有するブラッグ反射領域で光学的に結合した半導体レーザ装置。

## 3. 発明の詳細な説明

## 〔発明の利用分野〕

本発明は光通信用光源や分光用光源に用いられる高出力半導体レーザ装置に関するものである。

## 〔発明の背景〕

半導体レーザ装置の高出力化をはかる従来の手段としては、複数個の半導体レーザ素子を並置し、かつこれらのレーザ素子同士を光学的に結合して達成させることがよく知られている。しかし単一モードの半導体レーザ装置では単なる光学的結合により高出力化することが困難であり実用化され

ていない。

## 〔発明の目的〕

本発明は、高出力動作が可能な縦単一モードの半導体レーザ装置を得ることを目的とする。

## 〔発明の概要〕

上記の目的を達成するために本発明による半導体レーザ装置は、横モード制御された複数個のレーザ発光部を同一面上に並置し、上記各レーザ発光部を周期性を有するブラッグ反射領域で光学的に結合したものである。

## 〔発明の実施例〕

つぎの本発明の実施例を図面とともに説明する。

第1図は本発明による半導体レーザ装置の一実施例を示す平面図、第2図は上記実施例のA-A断面図、第3図は上記実施例のB-B断面図である。上記実施例に示す半導体レーザ装置はレーザ発光部1と回折格子部2とにより構成されている。レーザ発光部1はそれぞれ横モード制御されたレーザ発光部1a~1eからなり、各レーザ発光部における断面構造の一例を第2図に示す。本実施例

はn型InP結晶3上に、He-Cdレーザによる干渉露光法を用いてピッチ2300Å、深さ800Åの回折格子31を作成したのち、液相エピタキシャル法を用いてInGaAsPガイド層4(アンダー、厚さ0.2~0.4μm、組成λ9~1.3μm相当)を形成した。つぎに第1のH<sub>2</sub>SO<sub>4</sub>系エッチング液(H<sub>2</sub>SO<sub>4</sub>:H<sub>2</sub>O:H<sub>2</sub>O<sub>2</sub>=1:1:8)を用いてInGaAsPガイド層4を選択的にエッチングして除去したのち、上記除去部についてはさらに第2のH<sub>2</sub>SO<sub>4</sub>系エッチング液(H<sub>2</sub>SO<sub>4</sub>:H<sub>2</sub>O:H<sub>2</sub>O<sub>2</sub>=5:1:1)を用いてエッチングして回折格子31を消失させた。この結晶に再度液相エピタキシャル法を用いて、InGaAsP活性層5(アンダー、厚さ0.1~0.2μm、組成λ9~1.5μm相当)、InGaAsPアンチメルトバック層6(アンダー、厚さ0.1μm、組成λ9~1.3μm相当)、p型InPクラッド層7(Znドーブ、キャリア濃度1×10<sup>18</sup>cm<sup>-3</sup>、厚さ3~4μm)、p型InGaAsP表面層8(Znドーブ、キャリア濃度5×10<sup>18</sup>cm<sup>-3</sup>厚さ0.2μm、組成λ9~1.15μm相当)を順次成長させて、レーザ発光部1にダブルヘテロ構造を形成した。その後

上記実施例におけるレーザ発光部1が20個のBH構造部からなる半導体レーザ装置において、出力が100mWまでの単一モード動作が可能であった。

上記実施例ではn型InP結晶3上に回折格子31を形成し、InGaAsPガイド層4を設けたのち、上記ガイド層4を選択的にエッチングで除去し、この除去部の回折格子31を再度エッチングして除いた結晶に、液相エピタキシャル法により活性層5、アンチメルトバック層6、クラッド層7、表面層8を順次積層して半導体レーザ装置を形成したが、他の方法、例えばn型InP結晶3上にガイド層4、活性層5、アンチメルトバック層6、クラッド層7、表面層8を液相エピタキシャル法で順次積層したのち、選択エッチングにより部分的に上記活性層5までを除去し、この除去した部分に回折格子31を形成してInGaAsPガイド層4を積層し、その上に上記各半導体層を順次積層して埋込むことによって半導体レーザ装置を形成しても、上記実施例と同じ構造を有するため同様の作用効果が得られる。

上記レーザ発光部1に幅6μmのストライプ状のSiO<sub>2</sub>膜を間隔5~50μmごとに形成し、このSiO<sub>2</sub>膜をマスクにしてBrメタノール溶液で蝕刻したのち液相エピタキシャル法で積層する通常のBHレーザ装置形成法と同様の手法で、第3図にB-B断面図として示すようなフィラメント状発光部を屈折率が小さい結晶で囲まれたBH構造を得た。このBH構造の埋込み部はp型InP層71(Znドーブ、キャリア濃度1×10<sup>18</sup>cm<sup>-3</sup>、厚さ0.8μm)、n型InP層72(Teドーブ、キャリア濃度1×10<sup>18</sup>cm<sup>-3</sup>、厚さ2~3μm)、InGaAsP表面層73(アンダー、厚さ0.2~0.3μm、組成λ9~1.15μm相当)とした。上記のレーザ結晶を作成したのち、p側電極9(Au/Cr)およびn側電極10(Au/Sn)を蒸着により形成し、へき開を行って半導体レーザ装置を形成した。上記の構造により同一面上に並置され横モード制御されたレーザ発光部が、その光電界がおよぶ範囲で、周期性を有するブラッグ領域で結合されているため、縦単一モードのレーザ発振を高出力化することができる。

また上記実施例はInGaAsP/InP系について記したが、例えばGaAlZAs/GaAs系など結晶の材料は限定しない。

#### 〔発明の効果〕

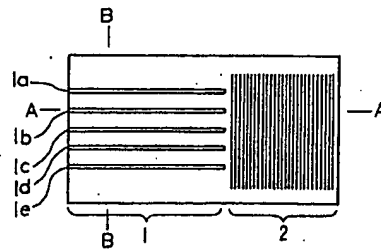
本発明による半導体レーザ装置は、横モード制御された複数のレーザ発光部を同一面上に並置し、上記各レーザ発光部を周期性を有するブラッグ反射領域で光学的に結合したことにより、結合された上記レーザ発光部の数に対応して縦単一モードのレーザ発振を高出力化することができるため、光通信用光源に用いた場合には100km以上の長距離光通信を可能にする半導体レーザ装置を得ることができる。

#### 4. 図面の簡単な説明

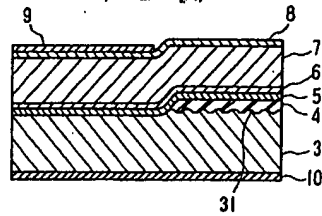
第1図は本発明による半導体レーザ装置の一実施例を示す平面図、第2図は上記実施例のA-A断面図、第3図は上記実施例のB-B断面図である。

1a、1b、1c、1d、1e…レーザ発光部、31…回折格子(ブラッグ反射領域)。

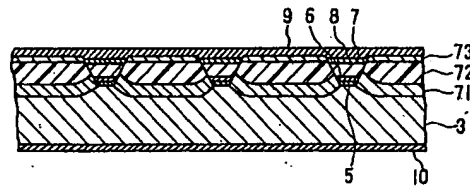
第 1 図



第 2 図



第 3 図



第 1 頁の続き

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